MIDSUMMER APPLICATIONS OF NITROGEN FERTILIZER BROADCAST ON NITROGEN DEFICIENT FIELDS

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April, 1959

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MIDSUMMER APPLICATIONS OF NITROGEN FERTILIZER BROADCAST ON NITROGEN DEFICIENT FIELDS

A DISSERTATION

SUBMITTED TO THE FACULTY OF GRADUATE STUDIES

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by

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ABSTRACT

To determine the effect of midsummer nitrogen fertilization on fields showing symptoms of acute nitrogen deficiency, broadcast applications of ammonium nitrate fertilizer were made at several locations in north-central Alberta. Twenty, forty, and sixty pounds of nitrogen per acre were applied in late June and early July on both barley and oats. Samples were harvested for yield determination and the grain was analyzed for nitrogen content.

Grain yields were influenced by applications of nitrogen made in the early stages of crop growth while increased nitrogen content of the grain resulted from the applications being delayed until the shot-blade stage or later. On the basis of yield alone, profitable increases were obtained at fifty per cent of the trial locations in one year of the experiment, and at seventy-five per cent of the locations in the other year.

Soil samples from the plot locations were analyzed for nitrate content, nitrate accumulation, total nitrogen, and organic matter. Very poor correlation existed between the laboratory analyses and crop response, indicating that none of the laboratory methods used in this investigation offers any promise for predicting crop response to mid-summer nitrogen fertilization.

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INTRODUCTION

In recent years an acute nitrogen deficiency has shown up in certain areas in north-central Alberta. This deficiency is apparent in late June and the early part of July. It indicates that the supply of nitrogen available in the soil is insufficient to meet the needs of the growing crop.

A nitrogen deficiency in cereals is characterized by a chlorotic condition, or pale yellow-green color of the crop. In later stages a browning and dying of the lower leaves occurs. This browning of the lower leaves is caused by the translocation of nitrogenous compounds to the more actively growing areas of the plant. As the plant matures with a continued nitrogen deficiency, growth is stunted, heads are extremely small, and yields are decreased considerably (30).

The objectives of the present investigation were to determine the effect on the crop of a broadcast application of nitrogen fertilizer after the deficiency symptoms have become apparent, and to determine the degree of correlation between soil tests and the magnitude of crop response.

LITERATURE REVIEW

Effect of Nitrogen on Plant Characteristics

Coic, Coppenet, and Helias (9) have stated that the yield of cereals is a function of three components: (a) the number of heads produced per unit area; (b) the average number of kernels per head; (c) the average kernel weight. Of the three components, the number of heads per unit area was said to exert the largest influence on yields. The role played by nitrogen in affecting these three components of yield has been discussed by many authors.

Rankin (34) has shown that the number of spikes per row of winter wheat was greatly increased by an application of nitrogen in April. Hobbs (25) also reported an increase in tillering of up to 20 per cent after a spring top-dressing of nitrogen to winter wheat. This increase in tillering was highly correlated with an increase in yield. McNeal and Davis (31) have shown that the number of tillers in spring wheat was increased 69 per cent by the addition of one hundred pounds of nitrogen at seeding, and the corresponding yield increase was 114 per cent.

The addition of nitrogen in February or March to winter wheat with a subnormal number of heads per unit has been reported by Coic *et al.* (9) to promote increased tillering which resulted in yields being increased by 70 per cent. If the application of nitrogen was delayed considerably,

new tillers were still formed, but only rarely did they produce mature grains by harvest time.

These results are all in agreement with the conclusions of Tzerling (44) who stated that a lack of nitrogen in the early growth stages reduced meristematic activity of the stem, whereas a high level of nitrogen prolonged meristematic activity with the production of a greater number of tillers and fertile grains. He stated that the magnitude of the effect of nitrogen additions depended on the developmental phase of the plants at the time the nitrogen was supplied. The largest yield increases were obtained when a high level of nitrogen was supplied at the time of the differentiation of the inflorescence, or about the three-leaf stage in wheat.

The number of kernels developing in the head is apparently dependent on an adequate supply of nutrients while the head is developing. Rankin (34) has shown that the largest number of kernels per head was produced by winter wheat when nitrogen was applied in small increments all through the early growth stages. The fertility of the spike was also influenced positively by additions of nitrogen at seeding time and in February. Coic and Jolivet (10) and Coic, Coppenet, and Helias (9) have reported that the number of kernels per head was increased by an addition of nitrogen at flowering time. This was presumed to be brought

about by reducing the number of fertile ovules which failed to develop into mature grains. This increase in the number of developing mature grains was in the order of 5 to 15 per cent.

A late application of nitrogen at about the flowering stage was reported by Coic et al. (9) and Garner (18) to produce an increase in the size of grains, and in the average kernel weight.

An interesting study was conducted by Thorne and Watson (43) on the leaf area of wheat at different stages of growth. They have stated that since the synthesis of carbohydrates and protein is dependent on energy received from sunlight through the leaves, the area of the green portion of the leaves has an important bearing on the amount of photosynthetic activity taking place. The leaf area index was found to be at a maximum in June just before heading, but declined rapidly from then until maturity due to the translocation of nitrogenous compounds to the seeds. They stated, however, that climatic conditions in late June and early July are such that maximum photosynthesis could occur during this period when the grain is filling and ripening. The application of nitrogen in the form of sprays was found to increase considerably the leaf area of the plants. A late application near the heading stage gave a small increase that was maintained for a considerable period of time,

while earlier applications gave larger increases in leaf area, which lasted for shorter periods of time.

An increase in the available supply of nutrients at such time as to provide the maximum leaf area for photosynthesis seems necessary to obtain maximum growth of the crop. It was shown by Coic (6, 7) that a large increment of nitrogen early in the growth of the plant stimulated vegetative growth so much that the later nutrient requirements of the plant were greatly increased. If this larger requirement was not met, a reduction in yield was inevitable. A supplementary addition at a later stage of growth should provide the necessary nutrients for the plant to take full advantage of its growth potential. For this reason, he stated, nitrogen fertilization should not be carried out in an arbitrary manner, but the physiological needs of the plant should be met at each stage of its growth.

Effect of Nitrogen on Yield

Foote and Batchelder (17), studying the effect of nitrogen on the yield of barley, found that nitrogen, applied either as ammonium nitrate or urea, gave the largest yield increases when applied at seeding time or in the very early stages of growth. Later applications up to heading time resulted in progressively lower yield increases. Smith (38), Pedersen (33), and Carles *et al.* (5) have reported similar findings on both spring and winter wheat as well as other cereals in Kansas, Norway, and France, respectively.

From Rothamsted, Garner (18) has reported that all top-dressings of nitrogen to winter wheat between November and May had about the same effect on yields. The earlier applications increased the number of spikes per plant, while later applications increased the size of the kernels. Rankin (34) has stated that highest yields were obtained with winter wheat in North Carolina when the nitrogen was applied in small increments throughout most of the growing period of the plants. Applications of nitrogen at seeding time and in February were also responsible for sizeable increases.

From the results of pot tests in Germany, Achtnich (1) concluded that both barley and oats were able to tolerate a moderate deficiency of nitrogen in the early stages of growth. After an early nitrogen deficiency, the application of nitrogen caused very rapid root development and new tiller formation leading to nearly normal grain yields.

Effect of Nitrogen on Protein Content

Several workers reported that nitrogen fertilizers are ineffective in increasing the protein content of cereals. Rennie (35) and Hedlin et al. (24) have reported that no significant differences in protein content were obtained due to fertilizer treatments in certain trials in Saskatchewan and Manitoba. Russell et al. (36) have shown that in southern Alberta applications of more than forty pounds of nitrogen per acre were required to increase the protein content

of spring wheat, with a maximum of eighty pounds being required in some cases. These workers were all dealing with the application of fertilizer at seeding time. This ineffectiveness is understandable on the basis of the foregoing discussion since much of the nitrogen supplied at seeding time would be readily available to the crop in the earliest stages of development and would be used largely for vegetative growth. The supply of nitrogen at the time of filling of the grains would be greatly reduced with the result that less nitrogen would be available for the formation of protein. Other workers, particularily in Europe, have dealt with additions of fertilizer later in the growing season and have obtained more positive results. Many of these workers have also dealt with the quality of the protein produced.

Long and Sherbakoff (29) have shown that in Tennessee when the application of nitrogen fertilizer to winter wheat was delayed until May, the resulting crop had a significantly higher protein content. This increased protein was also of superior milling quality, the kernels being harder as measured by the pearling index. Higher rates of nitrogen at all dates of application gave consistently harder kernels than lower rates. Borowkowski and Kozera (3) reported that on experiments with oats in Poland, the highest protein content and best quality of grain were obtained when all the nitrogen fertilizer was applied shortly before heading. These late applications decreased the yield of grain somewhat

while increasing the protein content. Similar results have been reported by Hobbs (25) in Kansas, Gros (19) and Coic (6) in France, Pedersen (33) in Norway, and Widdowson et al. (47) and Garner (18) at Rothamsted.

Coic and Alexinsky (8) reported that late nitrogen fertilization of wheat contributed to an increase in the assimilating power of the leaves, and produced a considerable increase in the nitrogen content of the grain. The milling and baking qualities were increased only if the gluten content was raised as well as the total protein content. Such an increase in gluten content along with total protein was reported by Koblet and Vogelli (26) in Germany.

A recent technique used for increasing the nitrogen content of grain has been the use of foliar sprays of urea and other nitrogen compounds. Ferencz (14) has reported that such applications of nitrogen in the form of sprays were almost as effective as the application of an equivalent amount of nitrogen broadcast on the soil. An increase in protein content of 33 per cent was reported for the foliar application as compared to an increase of 40 per cent resulting from the broadcast application.

An intensive study of the effect of sprays on increasing the protein content of wheat has been made by Finney et al. (15). A single spray at flowering time increased the protein content from 10.8 per cent to 15.2 per cent. There was no apparent lowering of the baking quality of this

increased protein. More striking increases were obtained by the use of fifteen successive sprays at intervals of two or three days. This treatment increased the protein content of the wheat to 21 per cent, but this protein was judged to be somewhat inferior from a quality standpoint.

It is apparent from the literature reviewed thus far that for the production of good quality, high yielding crops, attention must be paid to the nitrogen nutrition of the crop at all stages of its growth. The provision of a readily available source of nitrogen at seeding time, as is the general practice where fertilization is practiced in western Canada, may not supply sufficient nitrogen for the later development and filling of the grain. Provision of a source of nitrogen later in the growing season, either by an application of fertilizer or by the decomposition of adequate plant residues, appears to be necessary for high quality grain production.

Methods of Determining Nitrate Accumulation in Soils

The classical method of determining nitrate accumulation in soils is the "tumbler" or "beaker" method. The method consists of placing the soil in a tumbler or beaker, bringing it to optimum moisture content, incubating, and determining the accumulated nitrate. The development of the procedure was attributed to Lipman and Brown by Waksman (46). Lipman and Burgess (28) and Harper and Boatman (22) have reported using this method.

According to Waksman (46) this method was used extensively in the early part of the century, but because of lack of correlation with field data, the method has been largely abondoned.

In recent years, however, a renewed interest has developed in incubation techniques and several modifications of the method have been proposed. Saunder, Ellis, and Hall (37) incubated their samples in small erlenmeyer flasks rather than in the classical beaker or tumbler. This facilitated the subsequent analysis for accumulated nitrate. A similar procedure which employed sixteen-ounce shaker bottles for the incubation procedure was proposed by Synghal (42). Large pyrex test-tubes were used by Calder (4) and placed in a tightly closed water bath which maintained the temperature at a constant level and also kept the atmosphere in the chamber saturated so as to minimize evaporation from the samples.

Other workers have suggested apparatus which allows the sample to be leached free of nitrate prior to incubation. This eliminates the necessity for a separate nitrate determination prior to incubation so that only the accumulated nitrate need be determined. Kresge and Merkle (27) proposed the use of Gooch crucibles fitted with asbestos pads. With this apparatus they were able to remove the accumulated nitrate at intervals of two weeks, using the same samples for successive incubations during ten or twelve weeks. Stanford and Hanway (39) have suggested the use of filter tubes, while other

workers (11, 13) have turned to glass or plastic vials with holes drilled in the bottom.

The physical conditions of the soil has been of concern to some workers. To provide porosity, and to alleviate compaction following leaching, the use of an equal volume of quartz sand mixed with the soil was proposed by Kresge and Merkle (27). Vermiculite was chosen by Stanford and Hanway (39) to promote aeration and to increase the water-holding capacity of the soil sample. The use of vermiculite mixed with the soil, as proposed by the above workers was found to be satisfactory by Cook, Warder, and Doughty (11), but was modified by Eagle and Matthews (13) because of poor reproducibility. They placed the soil between two layers of vermiculite so that the physical conditions of the soil would not be altered, while the moisture-holding capacity of the vermiculite was still utilized.

It is readily apparent that many of the conditions used in nitrification tests are of an empirical nature. Because of this, the use of such a test has been questioned by Harmsen and Van Schreven (20). They state that incubation tests provide only an estimate of the potential nitrifiability of the soil, while under field conditions the actual nitrifiability may be quite different. However, the use of such a test, even under the empirical conditions necessitated in the laboratory, is warranted if the results can be properly calibrated and correlated with actual field results.

Correlation of Soil Tests with Crop Response to Nitrogen Fertilizers

Fitts et al. (16) have demonstrated a moderate correlation between the nitrification rate of soils and the response of corn to nitrogen fertilizers. A good correlation has been reported by Munson and Stanford (32) between nitrification rate and the "N" value -- a measure of available soil nitrogen as determined in the greenhouse. Using similar methods and working with Alberta soils, Synghal (42) has shown only moderate correlation between nitrification rate and "N" values, and between nitrification rate and yield response to nitrogen fertilization. Correlations obtained in the greenhouse, however, could not be duplicated using the data from field trials. Cook, Warder, and Doughty (11) have reported fairly good correlation between the percentage yield of wheat grown on Saskatchewan soils and the nitrification rate as determined by the procedure outlined by Stanford and Hanway (39). The results of a modification of this procedure by Eagle and Matthews (13) have given fair correlation with the response to fertilizers by both oats and winter wheat in Ontario.

MATERIALS AND METHODS

Field Experiments

To determine the effect of broadcasting nitrogen fertilizer on cereals during the growing season, experiments were carried out during the summers of 1957 and 1958 on fields showing the typical chlorotic symptoms of nitrogen deficiency. These trials were located within a radius of 75 miles of Edmonton in north-central Alberta. Each trial consisted of strips of ammonium nitrate fertilizer applied at rates supplying 20, 40, and 60 pounds of nitrogen per acre. These strips of fertilizer, broadcast with a special applicator, were approximately 5 feet wide and 175 feet long. Check strips of approximately the same width were left between the fertilized strips.

At certain locations in 1958 a slight modification was made in the layout of the field trials. Two strips of triple superphosphate (0-45-0) were applied at right angles to, and crossing the nitrogen and check strips. The fertilizer was applied at rates supplying 20 and 40 pounds of phosphate (P_2O_5) per acre. These strips were applied to determine if a midsummer application of phosphate fertilizer would affect the maturity of the crop.

A list of the farmers cooperating in these trials, as well as some other general information, is found in Table I. The fertilizer was applied between June 18 and July 12 in 1957, and between June 20 and July 9 in 1958.

TABLE I. General Information Concerning Field Trials

Trial No.	Farmer	Legal Location	Soil Zone	Date of Fertilizer Application
1957				
Barley				
57- 1	Borys-early	SE 29-49-25-4	Black	June 18
57- 2	Borys-late	SE 29-49-25-4	"	July 5
57- 3	Champagne	SE 33-56-25-4	"	July 4
57- 4	Doering	SE 14-46-25-4	"	July 5
57- 5	Feldberg	SE 13-46-25-4	"	July 8
57- 6	Ferster-early	SW 33-49-26-4	"	June 21
57- 7	Ferster-late	SW 33-49-26-4	"	July 12
57- 8	Forth	NE 11-46-25-4	"	July 6
57- 9	Forth	NE 11-46-25-4	"	July 8
57-10	Goertz-early	SE 34-53-28-4	"	June 29
57-11	Goertz-late	SE 34-53-28-4	"	July 16
57-12	Hayduk	SE 36-49-27-4	"	June 21
57-13	Himschoot	SW 3-56-25-4	"	July 9
57-14	Johns	S 13-44-25-4	"	July 8
57-15	Kozial-early	SW 32-49-27-4	"	June 27
57-16	Kozial-late	SW 32-49-27-4	"	July 12
57-17	Ruff	NE 5-46-25-4	"	July 5
57-18	Sendziak	NE 19-49-27-4	"	June 21
57-19	Suder	SE 5-53-26-4	"	June 28
57-20	Wild	NW 34-52-26-4	"	June 28

(Continued)

TABLE I. General Information Concerning Field Trials (Continued)

Trial No.	Farmer	Legal Location	Soil Zone	Date of Fertilizer Application
57-21	Abraham	SW 3-60- 1-5	Deg.Bl.	July 9
57-22	Betts	NE 6-60- 1-5	"	July 10
57-23	Forcade	NW 22-57-25-4	"	July 4
57-24	Getzinger-early	SW 3-53- 1-5	"	June 29
57-25	Getzinger-late	SW 3-53- 1-5	"	July 16
57-26	Hauch	NE 4-60- 2-5	"	July 10
57-27	Litzenberger	NW 24-59- 3-5	"	July 9
57-28	Remple	NW 9-60- 3-5	"	July 10
57-29	Schleicher	SE 2-53- 2-5	"	July 2
57-30	Spilak	SW 35-49-26-4	"	June 18
57-31	Walter	NE 32-58- 4-5	"	July 10
57-32	Fontaine	SW 16-46- 1-5	Gr.Wooded	June 27
Oats				
57-33	Dickau	NE 18-46-24-4	Black	July 4
57-34	Kaup	NE 9-55-25-4	"	July 4
57-35	Wild	NW 34-52-26-4	"	June 28
57-36	Bateman	NE 30-58- 3-5	Deg.Bl.	July 10
57-37	Ciesla	SE 1-53- 2-5	"	June 29
57-38	Ford	SW 2-60- 1-5	"	July 9
57-39	Reschke-early	SW 4-53- 1-5	"	July 2
57-40	Reschke-late	SW 4-53- 1-5	"	July 16
57-41	Weist	NW 32-53- 7-5	"	July 3
Mixed Grain				
57-42	Florkewich	NE 10-53- 2-5	"	June 28

(Continued)

TABLE I. General Information Concerning Field Trials (Continued)

Trial No.	Farmer	Legal Location	Soil Zone	Date of Fertilizer Application
1958				
Barley				
58- 1	Halwa-early	NW 22-50-26-4	Black	June 25
58- 2	Halwa-late	NW 22-50-26-4	"	July 9
58- 3	Harysh	NE 23-50-26-4	"	June 25
58- 4	Hayduc	SE 36-49-27-4	"	June 30
58- 5	Litke	NW 36-49-26-4	"	June 19
58- 6	Smulski	NE 33-52-26-4	"	July 2
58- 7	Trelenberg	NW 26-51-24-4	"	July 3
58- 8	Wild-early	NW 34-52-26-4	"	June 27
58- 9	Wild-late	NW 34-52-26-4	"	July 9
58-10	Workun	SE 5-50-26-4	"	June 20
58-11	Fandrick	NE 36-49-26-4	Deg.Bl.	June 20
58-12	Getzinger	SE 3-53- 1-5	"	July 2
58-13	Neiman	SW 1-50-26-4	"	June 19
58-14	Remple	NW 9-60- 3-5	"	July 7
58-15	Wendell	SE 7-53- 1-5	"	June 27
58-16	Weisener-early	NE 17-49-25-4	"	June 20
58-17	Weisener-late	NE 17-49-25-4	"	July 9
58-18	Bogart	NW 6-48- 4-5	Gr.Wooded	June 30
58-19	Bogart	NW 6-48- 4-5	"	June 30
58-20	Dofka	NE 19-60- 3-5	"	July 8
58-21	Goldthorpe	NE 36-47- 3-5	"	June 30
58-22	Kiel	NW 7-60- 3-5	"	July 8
Oats				
58-23	Slaght	SW 2-53-26-4	Black	June 27
58-24	Doll	W 26-49-26-4	Deg.Bl.	June 20
58-25	Morrow	NE 33-59- 3-5	Gr.Wooded	July 8

At certain locations in both years, fertilizer was applied to strips adjacent to the original strips after an interval of approximately two weeks. Those trials where two applications were made are indicated by the notations "early" and "late" following the name of the farmer in Table I. These two applications were made to determine any differences in the effect of early and later applications.

Composite soil samples were taken at each plot location previous to the application of fertilizer. These soil samples, with the exception of a small portion from the 1958 trials, were air dried and crushed to pass a 2 mm. sieve, and then stored in plastic bags until required for laboratory analyses. The remaining portions of the 1958 samples were stored at field moisture condition in a refrigerator at 10°C. for two weeks prior to nitrate accumulation determinations which are described later.

In the fall, six one-square-yard samples were cut by hand from each of the fertilized and check strips at intervals of about 30 feet. These samples were allowed to cure indoors for about one week, dried, and then threshed. The resulting grain from each square yard sample was weighed for yield determination, and all samples from the same treatment in each trial were bulked for laboratory analyses.

An analysis of variance was carried out on the yield data from each trial; the data were analyzed as a randomized block experiment.

Laboratory Experiments

The nitrate content of the soil samples was determined by the phenoldisulphonic acid method as outlined by Harper (21). The concentration of nitrate in the final solutions was determined by reading the per cent transmittancy in a spectrophotometer and by comparison of these values with a standard curve rather than by color comparisons in Nessler tubes.

The nitrification rate of the soil samples was determined by three different methods in the case of the soils from the 1957 trials, and by five methods in the case of the soils from the 1958 trials. The procedure outlined by Synghal (42) was followed and is hereafter referred to as Method 1. Modifications of the procedure proposed by Stanford and Hanway (39) formed the basis of Method 2 and Method 3. Details of these procedures are given in the appendix. In Method 2, the nitrate initially present was removed from the sample by leaching with distilled water. Excess moisture was removed by regulated suction, and the sample was incubated for two weeks in a saturated atmosphere at 30°C. In Method 3, the nitrate originally present was not removed by leaching. The sample was brought up to optimum moisture and incubated according to the procedure of Method 2. To determine the accumulated nitrate in Method 3, the nitrate content of the original leachate from Method 2 was subtracted from the value obtained by Method 3 after incubation.

The above three methods were carried out on soil samples from all trials in both 1957 and 1958. Two additional methods were employed using the refrigerated soil samples from the 1958 trials. These methods, referred to as Methods 4 and 5 are modifications of the procedure proposed by Eagle and Matthews (13). Details are found in the appendix. The two methods vary only in length of the incubation period. Original nitrate was not removed by leaching; the samples were brought up to optimum moisture and incubated one week in the case of Method 4 and two weeks in the case of Method 5. The nitrate content of a separate sample was determined and subtracted from the value obtained on incubation to give the nitrate accumulated. A sample of the refrigerated soil was dried at 105°C. to enable calculations to be expressed on an oven-dry basis.

All determinations using Method 1 were carried out in duplicate, while triplicate samples were used for the other four methods.

Total nitrogen content of the soil samples was determined by the Micro-Kjeldahl procedure as outlined by St. Arnaud (40) and organic matter content of the soils was determined by the modification of the Walkley wet oxidation procedure given in the United States Department of Agriculture Handbook 60 (45).

The bulked grain samples were thoroughly mixed, subsampled, and ground to pass a 20 mesh sieve. The nitrogen content was then determined by the Kjeldahl method as outlined in A. O. A. C. (2) with the following modifications: (a) a commercial Kel-Pak catalyst was used rather than a salt mixture for digestion, and (b) distillation was done into 4 per cent boric acid solution followed by titration with standard sulphuric acid.

RESULTS AND DISCUSSION

Observations on Field Trials

It was observed that one or two weeks following the application of nitrogen fertilizer the chlorotic condition of the crop disappeared. The degree of darkness of the green color produced by the fertilizer was generally proportional to the rate of application. The application of forty and sixty pounds of nitrogen per acre consistently produced plants with a darker bluish-green color than did the twenty pound rate. Twenty pounds of nitrogen per acre appeared sufficient in all cases to produce healthy, normal plants.

The utilization of applied nitrate was greatly dependent on precipitation following application. Stewart and Eck (41) found that in Oklahoma surface applied nitrate was capable of moving as deep as five and one-half inches if the soil moisture was at field capacity, and to lesser depths when the soil moisture content was lower. They concluded that some utilization of surface applied nitrate could take place before an effective rain had fallen, but the maximum efficiency would not occur until rainfall had moved the nitrate into the root zone.

Observations of the trials were not made often enough to determine the exact time of precipitation, nor the length of time required for the fertilizer to produce an effect on the color of the plants. Very little use of nitrate

appeared to occur before the rain had washed the fertilizer down to the root zone. In some instances there were no visible effects for a period of almost three weeks due to a lack of precipitation at certain locations. This occurred at trials 58-6 and 58-12. At another location, trial 57-6, no effect of fertilizer was visible 13 days after fertilization and granules of fertilizer were still on the surface of the ground. Rain fell two days later, and six days following the rain good color differences were noted. It is apparent then that some precipitation is necessary following broadcast applications of nitrogen fertilizer before full utilization by the crop can occur.

Observations made four to six weeks following the earlier applications showed in many cases an increase in both the height and length of head of the fertilized plants. At several locations where no difference in height of the crop was noted, the heads were longer and much fuller than the unfertilized plants. No instances of increased stooling or second growth were noted.

Broadcast applications of fertilizer were found to aggravate the weed problem at many locations. This was especially true in those trials where the field was badly infested with weeds, or where spraying for weed control had not been carried out. In some cases considerable difficulty was experienced when harvesting samples by hand because of the increase in weeds. Nitrogen fertilizer broadcast on the soil

surface became readily available to all plant growth and not specifically to the cultivated crop.

Another very marked effect of the late applications of additional nitrogen was the delay in the maturity of the crop. As all trials had to be harvested before the cooperating farmer was ready to swath his crop, the trials could not be left until maturity. In most cases there was an estimated delay in maturity of from one to two weeks due to the added nitrogen. The delay in maturity was shown by green kernels and leaves, with the kernels still being in the soft dough stage, and occasionally the late milk stage. This effect was more pronounced for the heavier rates of fertilization.

It is possible that this delay in maturity may have resulted in a lowering of yields caused by shrinkage of immature kernels. Such an effect, if present, may not have been of great magnitude since Dodds and Dew (12) have shown that barley may be swathed with a moisture content as high as 40 per cent without a significant reduction in yield. Since the samples were left to cure for about one week before being dried and threshed, there was ample time for the maturation process to continue even though the plants had been cut.

The midsummer applications of phosphate fertilizer on certain trials in 1958 produced no visible effect on the maturity of the crop. These applications were made to determine whether or not the addition of some phosphorus along with a broadcast application of nitrogen would counteract the delay in maturity caused by the nitrogen. Because no effect

was visible, no samples were taken at harvest time from the plots which had received phosphate applications, and no data concerning the phosphate additions is presented. The added phosphorus undoubtedly had insufficient mobility to reach the root zone because of fixation in the top few inches of the soil.

Phosphate fertilizers had been applied to some of the plot areas in the spring at seeding time. The fertilizers used were 11-48-0 and 16-20-0 at rates varying from 20 to 50 pounds per acre. Such applications were made to 12 plot locations in 1957, and to 13 locations in 1958. At one location spring applied fertilizer appeared to influence the maturity of the crop. The strips which received midsummer applications of 20 and 40 pounds of nitrogen per acre were decidedly more advanced in maturity than the check strips. The strips where 60 pounds of nitrogen per acre had been applied were somewhat delayed in maturity. The delay caused by the highest rate of application was probably due to an imbalance in the nitrogen and phosphorus in the plant, the nitrogen being in excess. These observations were made on both trials 57-1 and 57-2, the early and late applications at the one location. At no other location did spring applied phosphate fertilizer appear to have any influence on the crop which received subsequent applications of nitrogen in midsummer.

It should be pointed out that in spite of the use of fertilizer in the spring at some of the plot locations, symptoms

of nitrogen deficiency appeared in the crop during the summer. The fertilizers had supplied from two to eight pounds of nitrogen per acre. This amount of nitrogen was insufficient to maintain satisfactory growth, particularily in view of the fact that, with one exception, the trials were located on fields which had not been summerfallowed the previous season. If higher rates of application had been used in the spring, the deficiency may not have become apparent.

When discussing the results of midsummer application of nitrogen fertilizer, no further consideration will be given to spring applied fertilizers since the whole plot area was treated uniformly in each case.

Data from Field Trials

The average yields from the field trials are shown in Table II. The notations N_{20}, N_{40}, and N_{60} refer to the rate of fertilization: 20, 40, and 60 pounds of nitrogen per acre, respectively. These notations are used in subsequent tables.

Table II shows that on the average, the yield of grain was increased by midsummer applications of nitrogen fertilizer, the average increases being greater for the higher rates of fertilization. The average yields of barley and oats from both years combined are shown in Table III. Again, the average increases are greater following the higher rates of fertilization.

A complete tabulation of yield data is presented in Table X in the appendix. Examination of these data shows that

TABLE II. Average Yields of Grain (cwt./acre) following Midsummer Nitrogen Application

		Check	Rate of Fertilization N_{20}	N_{40}	N_{60}
1957					
Barley	32 trials	10.3	12.8	13.6	14.6
Oats	9 trials	12.5	15.1	16.9	18.7
Mixed grain	1 trial	7.8	13.7	10.7	12.6
Mean yield	all trials	10.9	13.3	14.3	15.4
St. Dev.		4.6	4.7	5.6	5.9
1958					
Barley	22 trials	8.6	11.4	12.4	13.5
Oats	3 trials	9.7	15.6	17.3	20.1
Mean yield	all trials	8.7	11.9	13.0	14.3
St. Dev.		2.9	3.2	3.6	5.4

TABLE III. Average Yield (cwt./acre) of Barley and Oats following Midsummer Nitrogen Applications

		Check	Rate of Fertilization N_{20}	N_{40}	N_{60}
Barley	54 trials	9.6	12.3 (24)*	13.1 (31)	14.1 (37)
Oats	12 trials	11.8	15.2 (7)	17.0 (10)	19.1 (10)

* Number of significant increases ($p = 0.05$).

there is considerable variability in the effect of fertilizer on the yield of grain. Yield increases from the fertilizer treatments range from zero to well over 100 per cent of the check yield. This variability of effect will be discussed later.

The average nitrogen content of the grain following midsummer applications of nitrogen is shown in Table IV. These data show that on the average the nitrogen content of the grain has been increased due to nitrogen fertilization, the higher rates producing greater increases in nitrogen content. A complete tabulation of the data on nitrogen content of the grain is given in the appendix in Table XI. Examination of these data again shows a wide range in effect. In some cases the nitrogen content has been increased by 75 per cent, while in others there is an actual decrease.

If the data in Tables X and XI are examined together, it is noted that where there are large increases in yield of grain, there are little or no increases in the nitrogen content; whereas when little or no effect is observed on the yield of grain, increases in the nitrogen content occur which are of considerable magnitude. For example, trials 57-17, 57-41, 58-5, and 58-10 all show a considerable increase in yield with very little difference in nitrogen content. On the other hand, trials 57-14, 57-21, 58-12, and 58-14 show very little increase in yield and extreme differences in nitrogen content.

TABLE IV. Average Nitrogen Content of Grain (per cent) following Midsummer Nitrogen Application (oven-dry basis)

		Check	Rate of Fertilization N_{20}	N_{40}	N_{60}
1957					
Barley	32 trials	1.64	1.88	2.11	2.28
Oats	9 trials	1.61	1.86	2.08	2.19
Mixed grain	1 trial	1.89	2.04	2.36	2.43
Mean nitrogen content	all trials	1.64	1.88	2.11	2.27
St. Dev.		0.15	0.26	0.33	0.31
1958					
Barley	22 trials	1.61	1.81	2.07	2.24
Oats	3 trials	1.55	1.73	1.91	2.14
Mean nitrogen content	all trials	1.60	1.80	2.06	2.23
St. Dev.		0.09	0.20	0.34	0.35

This interaction of yield and nitrogen content can be explained on the basis of the stage of plant growth when the fertilizer became available. If the fertilizer was broadcast at an early date, and rain fell soon thereafter, the nitrogen was available to the crop during its early growing period. This resulted in an increase in the height of the crop, length of head, number of kernels per head, and a subsequent increase in yield. If no rain fell following an early application, or if the application was not made until a late date with the fertilizer becoming available to the crop only in the later stages of growth, the effect was quite different. In this case, very little increase in yield occurred since vegetative growth had almost ceased. The kernels, however, were still filling and ripening, and the large amount of available nitrogen was effective in increasing the nitrogen content of the grain. An examination of the yield and nitrogen data from those trials where two applications were made at different dates substantiates this observation.

Because of the variability in the effect of the nitrogen fertilizer on both the yield and nitrogen content of the grain, a calculation was made to determine the yield per acre of nitrogen in the grain. This calculation was made so that the data from different trials could be more equitably compared. These data are found in Table XII in the appendix.

They show that despite the variability in both the yield and nitrogen content of the grain, there is a consistent increase in the yield of nitrogen per acre from the increasing rates of fertilization. The average yields of nitrogen per acre in the various crops are shown in Table V. These averages show a fairly substantial increase in the yield of nitrogen per acre in the grain. These increases will be discussed later.

Laboratory Analyses

The data for nitrate content, total nitrogen, and organic matter content of the soil samples are given in Table XIII in the appendix. The nitrate content, with few exceptions is quite low, no doubt because the crop was actively growing in the soil at the time the samples were taken. This may partially explain the deficiency symptoms in the crop since analyses for nitrate in several other soil samples taken at the same time from fields not showing nitrogen deficiency gave values that generally exceeded 10 p.p.m. The levels of total nitrogen and organic matter are for the most part average for Alberta soils, so cannot be offered as explanations of nitrogen deficiency.

The nitrate accumulation by various methods is given in Table XIV in the appendix. There is some variation among the results of the different methods, probably due to the differences in handling the soil samples either in preparation for analysis or during the analysis itself.

TABLE V. Average Yield of Nitrogen (lb./acre) from Plots Receiving Midsummer Nitrogen Applications

		Check	Rate of Fertilization N_{20}	N_{40}	N_{60}
1957					
Barley	32 trials	17.6	23.8	28.0	32.0
Oats	9 trials	19.7	27.1	34.0	40.0
Mixed grain	1 trial	14.8	28.0	29.2	30.6
Mean yield of nitrogen	all trials	18.0	24.6	29.3	33.9
St. Dev.		7.8	7.8	10.2	11.3
1958					
Barley	22 trials	13.8	20.3	25.0	29.1
Oats	3 trials	14.8	26.7	32.7	42.4
Mean yield of nitrogen	all trials	13.9	21.1	25.9	30.7
St. Dev.		4.6	4.9	6.0	9.2

The agreement between duplicates in Method 1 was considered to be very good. Agreement between triplicate samples was quite poor in Methods 2 and 3, and fairly good in Methods 4 and 5. This is in agreement with Eagle and Matthew (13) who reported less variation between replicates following refrigeration of the soil samples (as was done in Methods 4 and 5).

Correlations

Scatter diagrams were plotted to determine the relationship existing between the results from field trials and laboratory tests with soil samples. Check yield, fertilized yield, yield increase over check, nitrogen content of the grain, and yield of nitrogen per acre for the various rates of fertilization were plotted against nitrate content of the soil, nitrate accumulation by the various methods, total nitrogen content, and organic matter content. These scatter diagrams were examined for evidence of correlation. None of the scatter diagrams appeared to indicate any practical degree of correlation. The data from some of the combinations which appeared to have a slightly better relationship than the majority were used for the calculation of correlation coefficients, or "r" values. Certain of these are given in Table VI. It was evident from the scatter diagrams that the remainder of the "r" values did not merit calculation.

The highest "r" value obtained, that between check yield in 1957 and nitrification Method 1, indicates that only

TABLE VI. Some Correlation Coefficients between Field Results and Soil Tests

Correlation between	r - value
Check yield and nitrification Method 1 - 1957	0.52**
Check yield and nitrification Method 1 - 1958	0.04
Check yield and nitrification Method 5 - 1958	0.28
Yield of nitrogen per acre and nitrification Method 1 - 1957	0.37*
Yield of nitrogen per acre and nitrification Method 1 - 1958	0.05

* and ** indicate significance at the 0.05 and 0.01 levels, respectively.

27 per cent of the variation in yield can be attributed to variation in the nitrate producing capacity of the soil as determined by Method 1. It is perhaps significant to point out that even when the effect of fertilizer had been leveled out by the calculation of yield of nitrogen per acre, very little correlation was shown with any of the laboratory analyses. Since the trials were all placed on fields showing the symptoms of nitrogen deficiency, it might be expected that conditions would be favourable for the detection of a correlation. Very poor correlation has been found, however, indicating that none of the laboratory methods used in this investigation offers any promise for predicting the effect of midsummer applications of nitrogen fertilizer to deficient fields.

There is considerable difference in the "r" values obtained between check yield and nitrification Method 1 in the two years of the experiment. A value of 0.52 was obtained in 1957 while a value of 0.04 was obtained in 1958. This difference in the degree of correlation is probably due to the length of time between sampling and the completion of analyses. Determinations of nitrate accumulation on the 1957 samples were not run until about 8 months after the samples had been taken, whereas all analyses on the 1958 samples were completed within about 4 months. Similar results are reported by Harpstead and Brage (23) who have stated that no correlation was obtained between response of oats to

nitrogen fertilization and nitrate accumulation in soils stored for less than 18 weeks, whereas for the same soils stored longer than 18 weeks, moderate correlation was obtained.

The correlation of all laboratory tests on nitrate accumulation with field data may have been affected somewhat by this factor. If such were the case, it would prove extremely impractical to store soil samples for a period of 4 or 5 months prior to analysis. The results obtained would be of no use to the crop growing on the field when the samples were taken, and would be of questionable value for the succeeding crop.

Since several methods of determining the nitrification rate of the soil samples were used in this study, the correlation between methods was determined. The data for various combinations of the different methods employed were plotted in scatter diagrams and the diagrams examined for evidence of correlation. Correlation coefficients were calculated for some of the combinations and are given in Table VII. It is evident from these values that good correlation exists between related methods, while correlation is much poorer between unrelated methods. The term "related methods" refers to methods in which the procedures employed are very similar with only minor variations. For example, Methods 2 and 3, 4 and 5 are considered to be related, while Methods 1 and 2, 2 and 4, etc. are considered to be unrelated because of differences in the procedure.

TABLE VII. Some Correlation Coefficients between Methods of Determination of Nitrate Accumulation

Correlation between	r - value
Methods 1 and 2 - 1957	0.62 **
Methods 1 and 2 - 1958	0.18
Methods 1 and 4 - 1958	0.36
Methods 2 and 3 - 1957	0.89 **
Methods 2 and 3 - 1958	0.94 **
Methods 2 and 4 - 1958	0.23
Methods 4 and 5 - 1958	0.83 **

** indicates significance at the 0.01 level.

Some Practical Considerations

The nitrogen content of plant material is generally taken as an index of its "crude" protein content. Tables IV and V have shown the average increases in nitrogen content of the grain, and the average increases in yield of nitrogen per acre following midsummer applications of nitrogen fertilizer. These averages indicate a sizable increase in the protein content of the grain, and in the yield of protein per acre. Such increases in protein yield could prove to be of considerable importance, especially in those areas where the major portion of the grain produced on the land is used as a livestock feed. Depending on the nature and feeding value of the protein produced, midsummer applications of nitrogen fertilizer could influence the profitability of a livestock enterprise.

Since, however, no information is available on the feeding value of the additional protein produced, it is extremely difficult to give adequate consideration to the economics of the question. The following discussion then will be limited only to the economics of the yield increases obtained, and not to a consideration of the value of the increased protein.

The cost of nitrogen fertilizer in the Edmonton area is currently about 13 cents per pound of nitrogen.

Assuming the value of grain to be about 2 cents per pound, it is possible to calculate the profitability of midsummer applications of nitrogen fertilizers. The results of these calculations are shown in Table VIII. This table shows the cost of fertilizer for the various rates of application and the profit realized from the increased production of grain. These calculations are based on the average yield increases obtained from all trials in both 1957 and 1958. They show that the most profitable rate of application was 20 pounds of nitrogen per acre. The larger profit in 1958 is attributed to greater discrimination having been used in selecting the sites for the 1958 trials. There were fewer fields which could be considered as "borderline" cases.

Table IX shows the number of trials in each of the two years at which profitable yield increases were obtained from the different rates of fertilization. Again it is seen that in 1958 a higher percentage of the trials showed profitable yield increases due to the greater selectivity in locating the trials.

It must be pointed out before concluding this discussion that all the above calculations are based on experiments carried out on fields showing symptoms of nitrogen deficiency. The application of nitrogen fertilizer

TABLE VIII. Cost of Nitrogen Fertilization and Estimated Profit from the Grain Produced

Rate of Fertilization	Cost of Application	Estimated Profit
1957		
N_{20}	$2.60	$2.20
N_{40}	5.20	1.60
N_{60}	7.80	1.20
1958		
N_{20}	2.60	3.80
N_{40}	5.20	3.40
N_{60}	7.80	3.40

TABLE IX. Percentage of Trials Showing Profitable Yield Increases from Midsummer Nitrogen Fertilization in 1957 and 1958

Year	Rate of Fertilization N_{20}	N_{40}	N_{60}
1957	50%	35%	30%
1958	75%	50%	45%

in midsummer to normal fields would show lower profits on the average, and a smaller percentage of profitable yield increases when considering the yield alone. Information on the nutritive value of the protein would, of course, change the economics of the situation considerably, but this is not considered because of lack of data.

CONCLUSIONS

On the basis of the results presented in the foregoing section, the following conclusions are drawn:

1. Midsummer broadcast applications of nitrogen fertilizer on crops showing nitrogen deficiency symptoms are instrumental in overcoming the deficiency and in returning the color of the crop to a normal dark green.
2. Broadcast applications of nitrogen fertilizer are of little value until rain has fallen and moved the fertilizer into the root zone.
3. Applications of nitrogen in the early stages of crop growth produce increased yields by promoting the growth of such vegetative portions of the plant as the heads, number of kernels per head, and the size of the kernels.
4. Applications of nitrogen in the later stages of growth increase the nitrogen content of the grain and thereby increase the crude protein content.
5. Yield of nitrogen in the grain per acre, and likewise yield of crude protein per acre, is increased by increasing rates of nitrogen fertilization regardless of whether the main effect of the fertilizer is on yield or on nitrogen content.
6. Midsummer applications of nitrogen fertilizer cause a delay in the maturity of the crop of one to two weeks.

7. Midsummer broadcast applications of phosphate fertilizer have no visible effect on the maturity of the crop.
8. Broadcast applications of nitrogen fertilizer aggravate the weed situation in badly infested fields, or in fields where spraying for weed control has not been done.
9. Laboratory analyses on soil samples conducted in this investigation, viz. nitrate content, nitrate accumulation by various methods, total nitrogen, and organic matter content show poor correlation with the results of field trials where nitrogen has been broadcast in midsummer. Such analyses provide no satisfactory means of predicting the crop response to late nitrogen fertilization.
10. From a practical standpoint, and considering yield alone, midsummer applications of nitrogen fertilizer are decidedly profitable on fields showing symptoms of nitrogen deficiency.

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APPENDIX

Procedures for Nitrate Accumulation Determination by Various Methods

All incubations are carried out in filter tubes 4 cm. in diameter, 8 cm. in height, with an 8 cm. stem.

Nitrate accumulation -- Method 2

1. Place a wad of glass wool in the bottom of the filter tube and hold in place with a few drops of distilled water.
2. Add 1 teaspoonful of vermiculite, followed by 10 grams of soil.
3. Wet the soil with 10 ml. of 0.02 per cent solution of Krilium to stabilize the soil colloids and aid filtration. Allow to stand for 15 minutes.
4. Add 1 teaspoonful of vermiculite over top of the soil layer.
5. Leach the sample with 6 - 25 ml. aliquots of distilled water to remove the nitrate present. Allow each aliquot to drain completely before adding the next one.
6. After leaching with 6 aliquots of distilled water, remove the excess water with suction regulated at a tension of 7.4 cm. of mercury. Save the leachate for the determination of original nitrate content according to steps 9 - 11 below.

7. Stopper the filter tube with a one-holed rubber stopper to prevent excessive evaporation, yet allow some circulation of air, and incubate in a saturated atmosphere for 2 weeks at 30°C.

Removal of accumulated nitrate

8. Leach the incubated sample with 6 - 25 ml. aliquots of distilled water allowing each to drain completely before adding the next. After leaching, remove the excess moisture with regulated suction as per step 6.
9. To the leachate add 1/2 teaspoonful of carbon black, 0.1 gram $Ca(OH)_2$, shake, and filter using Whatman #5 filter paper.
10. Place an aliquot in an evaporating dish and evaporate to dryness at 70°C.
11. Develop color and determine nitrate content by the phenoldisulphonic acid method (21).

Nitrate accumulation -- Method 3

1. Place a wad of glass wool in the bottom of the filter tube and hold in place with a few drops of distilled water.
2. Add 1 teaspoonful of vermiculite, followed by 10.0 grams of soil.
3. Wet the soil with 10 ml. of 0.02 per cent solution of Krilium and allow to stand for 15 minutes.

4. Add 1 teaspoonful of vermiculite over top of the soil layer.
5. Moisten the sample by adding distilled water until the upper layer of vermiculite, the soil layer, and the upper portion of the lower layer of vermiculite are wet.
6. Stopper the filter tube with a one-holed rubber stopper and incubate in a saturated atmosphere for 2 weeks at 30°C.
7. Following incubation, remove and determine the nitrate present according to steps 8 - 11 of Method 2.
8. To calculate the accumulated nitrate, subtract the value obtained from the first leaching (step 6, Method 2) in Method 2 from the value obtained in step 7 above.

Nitrate accumulation -- Method 4

1. Place a wad of glass wool in the bottom of the filter tube and hold in place with a few drops of distilled water.
2. Add 1 teaspoonful of vermiculite, followed by 15.0 grams of soil refrigerated at 10°C. for two weeks.
3. Wet the soil with 10 ml. of 0.02 per cent Krilium solution and allow to stand for 15 minutes.
4. Add 1 teaspoonful of vermiculite over top of the layer of soil.
5. Moisten the sample by adding distilled water until the

upper layer of vermiculite, the soil layer, and the upper portion of the lower layer of vermiculite are wet.

6. Stopper the filter tube with a one-holed rubber stopper and incubate in a saturated atmosphere at 30°C. for 1 week.
7. Following incubation, remove and determine the nitrate present following steps 8 - 11 of Method 2.
8. To determine the original nitrate content of the soil, prepare a separate sample according to steps 1 - 4 above, leach and determine nitrate content according to steps 8 - 11 of Method 2.
9. Subtract the value obtained in step 8 above from that obtained in step 7 to calculate the accumulated nitrate.
10. Oven-dry a sample of soil at 105°C. overnight for calculations based on oven-dry basis.

Nitrate accumulation -- Method 5

Follow the procedure outlined for Method 4. In step 6 incubate the sample for 2 weeks instead of 1 week.

TABLE X. Yield of Grain (cwt./acre) following Midsummer Nitrogen Applications

Trial No.	Check	Rate of Fertilization N_{20}	N_{40}	N_{60}	L. S. D. (p = 0.05) for comparing treatments	treatment vs. check
57- 1	8.4	13.2*	16.2*	22.6*	4.1	3.5
57- 2	8.4	15.8*	17.2*	19.3*	2.9	2.5
57- 3	8.8	9.5	10.6	10.2		
57- 4	12.8	16.7	19.6*	17.6*	4.7	4.1
57- 5	14.7	17.1	19.2*	19.3*	3.6	3.1
57- 6	8.3	10.9	11.4*	13.0*	3.3	2.9
57- 7	8.1	8.3	10.5	8.8		
57- 8	8.9	10.3	11.1	8.9		
57- 9	18.5	20.3	25.5	22.2		
57-10	11.7	16.8*	17.1*	18.2*	2.8	2.4
57-11	8.8	9.2	10.8	9.1		
57-12	8.4	13.6*	7.9	15.5*	2.4	2.2
57-13	12.0	11.5	10.2	15.5*	3.1	2.7
57-14	9.2	9.2	9.3	8.1		
57-15	14.2	15.8	15.3	16.4		
57-16	20.2	19.9	18.9	19.5		
57-17	5.5	14.2*	11.6*	9.6*	3.1	2.7
57-18	8.9	9.4	12.5*	13.6*	3.3	2.9
57-19	12.6	14.6	18.0*	23.4*	3.7	3.2
57-20	25.8	25.5	24.4	27.9		

(Continued)

TABLE X. Yield of Grain (cwt./acre) following Midsummer Nitrogen Applications (Continued)

Trial No.	Rate of Fertilization				L. S. D. (p = 0.05) for comparing	
	Check	N_{20}	N_{40}	N_{60}	treatments	treatment vs. check
57-21	6.2	8.0	7.3	7.6		
57-22	8.2	9.6	11.1	14.2*	4.3	3.7
57-23	7.5	9.2	10.0*	11.6*	2.5	2.2
57-24	8.6	9.7	10.3*	12.8*	1.7	1.4
57-25	7.4	7.9	7.8	7.6		
57-26	12.8	14.7	20.8*	17.4*	3.7	3.2
57-27	4.9	7.4*	7.3*	8.0*	1.6	1.4
57-28	7.1	8.9*	9.4*	8.7*	1.4	1.2
57-29	11.9	14.8	17.0*	16.9*	3.9	3.4
57-30	9.0	10.8	10.1	14.0*	2.5	2.2
57-31	10.1	12.6	13.3	12.7		
57-32	11.8	15.3*	12.0	17.1*	3.2	2.7
57-33	11.0	14.2	13.3	15.7		
57-34	18.6	22.6*	25.3*	27.5*	4.9	4.2
57-35	22.0	27.4*	27.7*	30.2*	5.7	4.9
57-36	4.7	11.0*	10.1*	16.3*	6.4	5.5
57-37	9.3	10.4	16.4*	15.6*	5.3	4.6
57-38	6.1	7.7*	7.7*	7.5*	2.2	1.9
57-39	12.6	14.7	15.6	16.9		
57-40	12.7	11.7	14.0	13.1		
57-41	15.1	16.2	22.1*	25.8*	6.3	5.5
57-42	7.8	13.7*	10.7*	12.6*	2.5	2.2

(Continued)

TABLE X. Yield of Grain (cwt./acre) following Midsummer Nitrogen Applications (Continued)

Trial No.	Rate of Fertilization				L. S. D. (p = 0.05) for comparing	
	Check	N_{20}	N_{40}	N_{60}	treatments	treatment vs. check
58- 1	4.8	7.9*	11.8*	12.6*	2.2	1.9
58- 2	6.2	7.5*	9.6*	9.5*	1.4	1.2
58- 3	8.6	13.8*	15.1*	19.0*	2.3	2.0
58- 4	6.7	8.2	10.2*	11.5*	1.8	1.6
58- 5	6.3	11.2*	14.6*	15.6*	2.0	1.7
58- 6	11.4	11.0	12.6	15.4*	2.4	2.1
58- 7	14.4	12.7	12.8	12.3		
58- 8	9.6	13.8*	14.2*	16.6*	3.0	2.6
58- 9	11.0	12.9	14.4	11.0		
58-10	5.6	12.5*	11.5*	12.0*	1.7	1.4
58-11	11.3	12.3*	16.8*	14.4*	2.5	2.2
58-12	4.8	7.0*	5.2	5.0	1.8	1.6
58-13	11.4	16.9*	14.6*	27.8*	3.1	2.7
58-14	6.8	8.8*	9.1	8.0*	1.4	1.2
58-15	5.5	6.8*	7.2*	7.1*	1.2	1.1
58-16	11.2	14.4*	15.2*	15.8*	2.8	2.4
58-17	8.8	11.7*	11.9*	11.4*	2.2	1.9
58-18	6.5	10.7*	11.3*	10.0*	2.6	2.3
58-19	6.4	13.9*	16.4*	15.3*	3.1	2.7
58-20	10.2	11.4	11.1	11.4		
58-21	10.5	15.2*	16.2*	20.0*	2.8	2.4
58-22	10.6	10.3	10.7	14.5		
58-23	4.5	20.1*	11.4*	13.9*	2.1	1.6
58-24	12.6	12.6	21.5*	26.2*	4.0	3.5
58-25	11.9	14.0*	18.9*	20.1*	3.0	2.5

* Significant increase over check (p = 0.05).

TABLE XI. Nitrogen Content (per cent) of Grain following Midsummer Nitrogen Applications (oven-dry basis)

Trial No.	Check	Rate of Fertilization N_{20}	N_{40}	N_{60}
57- 1	1.62	1.48	1.38	1.40
57- 2	1.62	1.70	1.81	1.86
57- 3	1.88	2.25	2.32	2.39
57- 4	1.48	1.63	1.86	1.94
57- 5	1.80	2.06	2.40	2.60
57- 6	1.70	1.91	2.27	2.41
57- 7	1.68	2.25	2.60	2.63
57- 8	1.90	1.99	2.34	2.67
57- 9	2.02	2.08	2.24	2.48
57-10	1.58	1.75	1.94	2.15
57-11	1.63	2.26	2.58	2.61
57-12	1.52	1.70	1.60	2.22
57-13	1.62	1.89	2.49	2.52
57-14	1.89	2.31	2.52	2.69
57-15	1.50	1.92	2.30	2.43
57-16	1.72	2.04	2.25	2.50
57-17	1.42	1.44	1.64	1.74
57-18	1.50	1.65	1.74	1.99
57-19	1.64	1.88	1.96	2.02
57-20	1.64	1.66	1.71	1.64

(Continued)

TABLE XI. Nitrogen Content (per cent) of Grain following Midsummer Nitrogen Applications (oven-dry basis)

(Continued)

Trial No.	Rate of Fertilization			
	Check	N_{20}	N_{40}	N_{60}
57-21	1.70	2.15	2.60	2.78
57-22	1.54	1.60	1.74	1.99
57-23	1.75	1.94	2.00	2.29
57-24	1.47	1.76	2.16	2.54
57-25	1.46	2.35	2.73	2.67
57-26	1.57	1.78	2.18	2.22
57-27	1.73	1.96	2.29	2.48
57-28	1.61	1.94	2.05	2.47
57-29	1.43	1.60	2.04	2.31
57-30	1.68	1.64	1.82	2.10
57-31	1.76	1.92	2.14	2.26
57-32	1.54	1.72	1.72	2.12
57-33	1.56	1.61	1.80	1.89
57-34	1.71	1.78	1.96	2.19
57-35	1.43	1.56	1.85	2.16
57-36	1.55	1.66	1.98	1.93
57-37	1.75	1.93	2.24	2.18
57-38	1.86	2.34	2.55	2.58
57-39	1.54	1.98	2.30	2.46
57-40	1.58	2.32	2.47	2.65
57-41	1.50	1.53	1.58	1.69
57-42	1.89	2.04	2.36	2.43

(Continued)

TABLE XI. Nitrogen Content (per cent) of Grain following Midsummer Nitrogen Applications (oven-dry basis) (Continued)

Trial No.	Rate of Fertilization			
	Check	N_{20}	N_{40}	N_{60}
58- 1	1.57	1.67	2.02	2.18
58- 2	1.56	1.92	2.46	2.66
58- 3	1.54	1.50	1.60	1.94
58- 4	1.48	1.66	1.90	2.05
58- 5	1.85	1.78	1.86	1.85
58- 6	1.78	1.88	2.20	2.44
58- 7	1.56	2.06	2.28	2.52
58- 8	1.60	1.67	1.81	2.03
58- 9	1.55	1.86	2.24	2.45
58-10	1.54	1.45	1.50	1.72
58-11	1.72	1.72	1.92	2.24
58-12	1.66	2.22	2.84	3.01
58-13	1.60	1.62	1.66	1.74
58-14	1.54	2.16	2.79	2.90
58-15	1.70	2.00	2.28	2.47
58-16	1.56	1.84	1.85	2.01
58-17	1.56	1.86	2.34	2.46
58-18	1.60	1.66	1.66	1.90
58-19	1.60	1.61	1.77	1.84
58-20	1.80	2.15	2.53	2.69
58-21	1.58	1.58	1.85	2.12
58-22	1.50	1.98	2.22	2.17
58-23	1.63	1.65	1.94	2.18
58-24	1.52	1.66	1.66	1.94
58-25	1.50	1.88	2.13	2.29

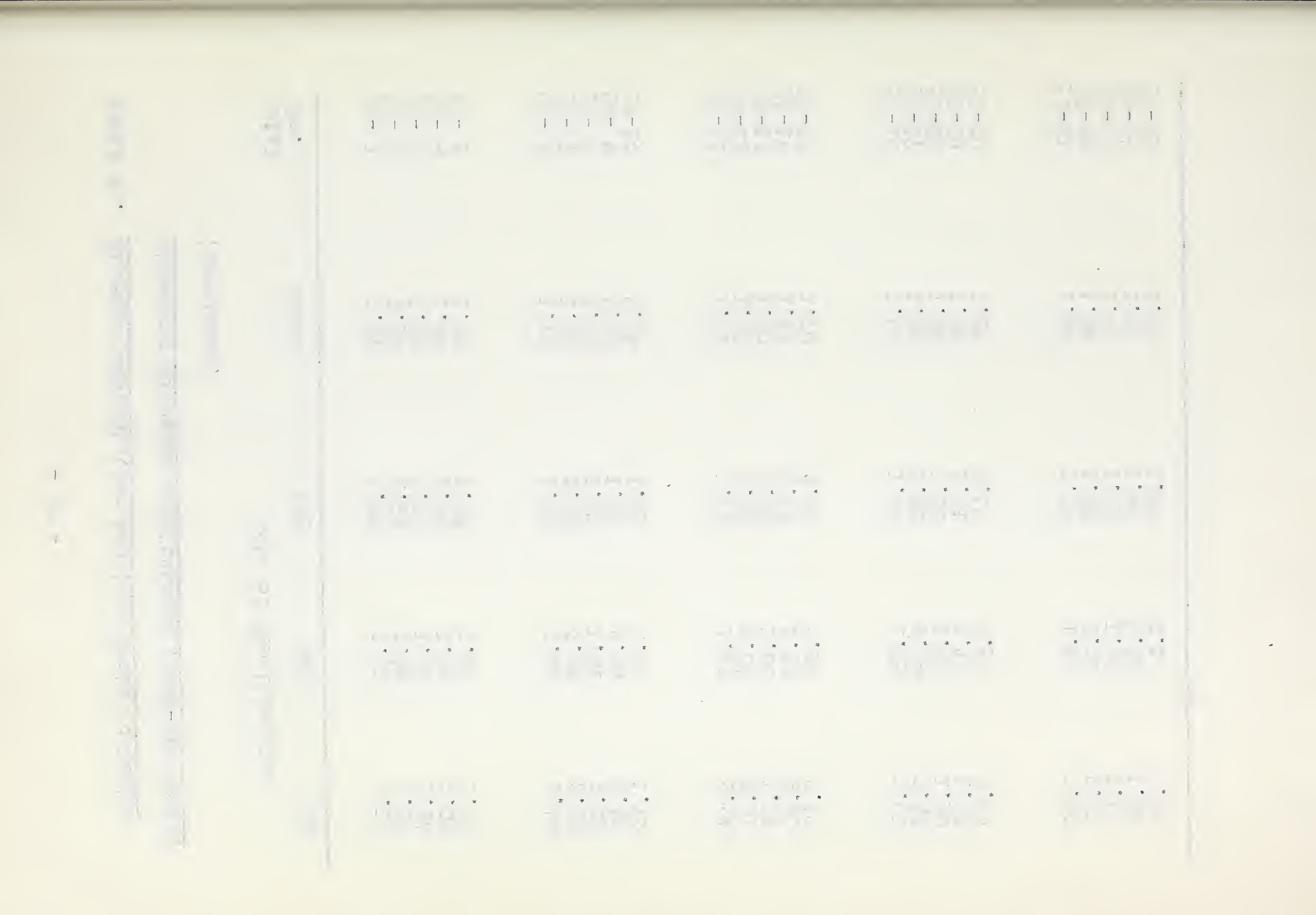

TABLE XII. Yield of Nitrogen (lb./acre) from Plots Receiving Midsummer Nitrogen Applications

Trial No.	Check	Rate of Fertilization N_{20}	N_{40}	N_{60}
57- 1	13.6	19.6	22.4	31.6
57- 2	13.6	26.8	31.1	35.9
57- 3	16.5	21.3	24.6	24.3
57- 4	19.0	27.3	36.4	34.1
57- 5	26.4	35.1	46.0	50.1
57- 6	14.1	20.8	26.0	31.3
57- 7	13.5	18.6	27.4	23.2
57- 8	17.0	20.4	26.0	23.8
57- 9	37.4	42.2	52.7	55.1
57-10	18.5	29.4	33.2	39.1
57-11	14.3	20.9	27.8	23.8
57-12	12.7	23.1	12.6	34.3
57-13	19.5	21.7	25.5	39.2
57-14	17.4	21.2	23.5	21.8
57-15	21.3	30.4	35.3	39.9
57-16	34.7	40.6	42.6	48.7
57-17	7.8	20.5	19.0	16.8
57-18	13.4	15.4	21.7	27.1
57-19	20.6	27.4	35.3	47.3
57-20	42.3	42.3	41.8	45.7

(Continued)

TABLE XII. Yield of Nitrogen (lb./acre) from Plots Receiving Midsummer Nitrogen Applications (Continued)

Trial No.	Check	Rate of Fertilization N_{20}	N_{40}	N_{60}
57-21	10.6	17.1	19.0	21.0
57-22	12.7	15.3	19.3	28.2
57-23	13.1	17.8	19.9	26.6
57-24	12.7	17.0	22.3	32.4
57-25	10.7	18.6	21.3	20.3
57-26	20.2	26.1	45.3	38.5
57-27	8.6	14.5	16.8	19.7
57-28	11.5	17.3	19.2	21.4
57-29	17.0	23.8	34.7	38.9
57-30	15.0	17.8	18.4	29.4
57-31	17.8	24.2	28.5	28.7
57-32	18.2	26.4	20.6	36.3
57-33	17.1	22.8	23.9	29.7
57-34	31.8	40.3	49.6	60.2
57-35	31.4	42.8	51.2	65.2
57-36	7.3	18.3	19.9	31.4
57-37	16.3	20.1	36.6	34.0
57-38	11.3	18.0	19.6	19.3
57-39	19.5	29.2	35.8	41.6
57-40	20.0	27.2	34.5	34.8
57-41	22.7	24.8	34.9	43.6
57-42	14.8	28.0	25.2	30.6

(Continued)

TABLE XII. Yield of Nitrogen (lb./acre) from Plots Receiving Midsummer Nitrogen Applications (Continued)

Trial No.	Check	Rate of Fertilization N_{20}	N_{40}	N_{60}
58- 1	7.6	13.2	23.8	27.4
58- 2	9.6	14.4	23.6	25.3
58- 3	13.2	20.7	24.1	36.9
58- 4	9.9	13.7	19.3	23.6
58- 5	11.6	19.9	27.2	28.8
58- 6	20.3	20.7	27.8	37.5
58- 7	22.5	26.1	29.2	31.0
58- 8	15.4	23.0	25.7	33.6
58- 9	17.0	24.0	32.2	27.0
58-10	8.5	18.1	17.3	20.7
58-11	19.4	21.1	32.3	32.3
58-12	8.0	15.5	14.6	15.1
58-13	18.2	27.4	24.2	48.4
58-14	10.5	19.1	25.4	23.3
58-15	9.3	13.6	16.5	17.6
58-16	17.5	26.4	28.2	31.8
58-17	13.8	21.8	27.8	27.9
58-18	10.4	17.7	18.8	19.1
58-19	10.2	22.4	29.0	28.2
58-20	18.4	24.4	28.2	30.8
58-21	16.5	24.0	29.9	42.5
58-22	15.9	20.4	23.8	31.5
58-23	7.4	33.1	22.2	30.3
58-24	19.2	20.8	35.7	50.9
58-25	17.8	26.3	40.2	46.0

TABLE XIII. Some Analytical Data for Soil Samples

(oven-dry basis)

Trial No.	Nitrate Content (p. p. m.) N as NO_3^-	Total Nitrogen (per cent)	Organic Matter (per cent)
57- 1	5	.35	7.1
57- 2	5	.35	7.1
57- 3	6	.61	9.5
57- 4	3	.50	10.3
57- 5	2	.83	16.0
57- 6	5	.34	6.4
57- 7	5	.34	6.4
57- 8	3	.48	10.2
57- 9	4	.48	10.3
57-10	5	.22	4.8
57-11	5	.22	4.8
57-12	12	.52	11.0
57-13	3	.48	9.6
57-14	2	.38	7.9
57-15	7	.54	12.6
57-16	7	.54	12.6
57-17	2	.36	8.6
57-18	7	.44	9.4
57-19	4	.30	6.5
57-20	3	.29	6.4

(Continued)

TABLE XIII. Some Analytical Data for Soil Samples

(oven-dry basis) (Continued)

Trial No.	Nitrate Content (p. p. m.) N as NO_3^-	Total Nitrogen (per cent)	Organic Matter (per cent)
57-21	2	.29	6.0
57-22	2	.46	9.5
57-23	4	.20	4.5
57-24	2	.12	2.9
57-25	2	.12	2.9
57-26	7	.20	5.1
57-27	9	.23	5.0
57-28	6	.26	6.5
57-29	10	.11	2.6
57-30	15	.32	7.3
57-31	5	.31	9.1
57-32	4	.12	3.0
57-33	1	.35	6.8
57-34	3	.38	7.8
57-35	3	.30	6.1
57-36	1	.22	5.6
57-37	9	.16	3.9
57-38	1	.21	4.9
57-39	2	.22	4.4
57-40	2	.22	4.4
57-41	2	.28	6.5
57-42	2	.20	4.3

(Continued)

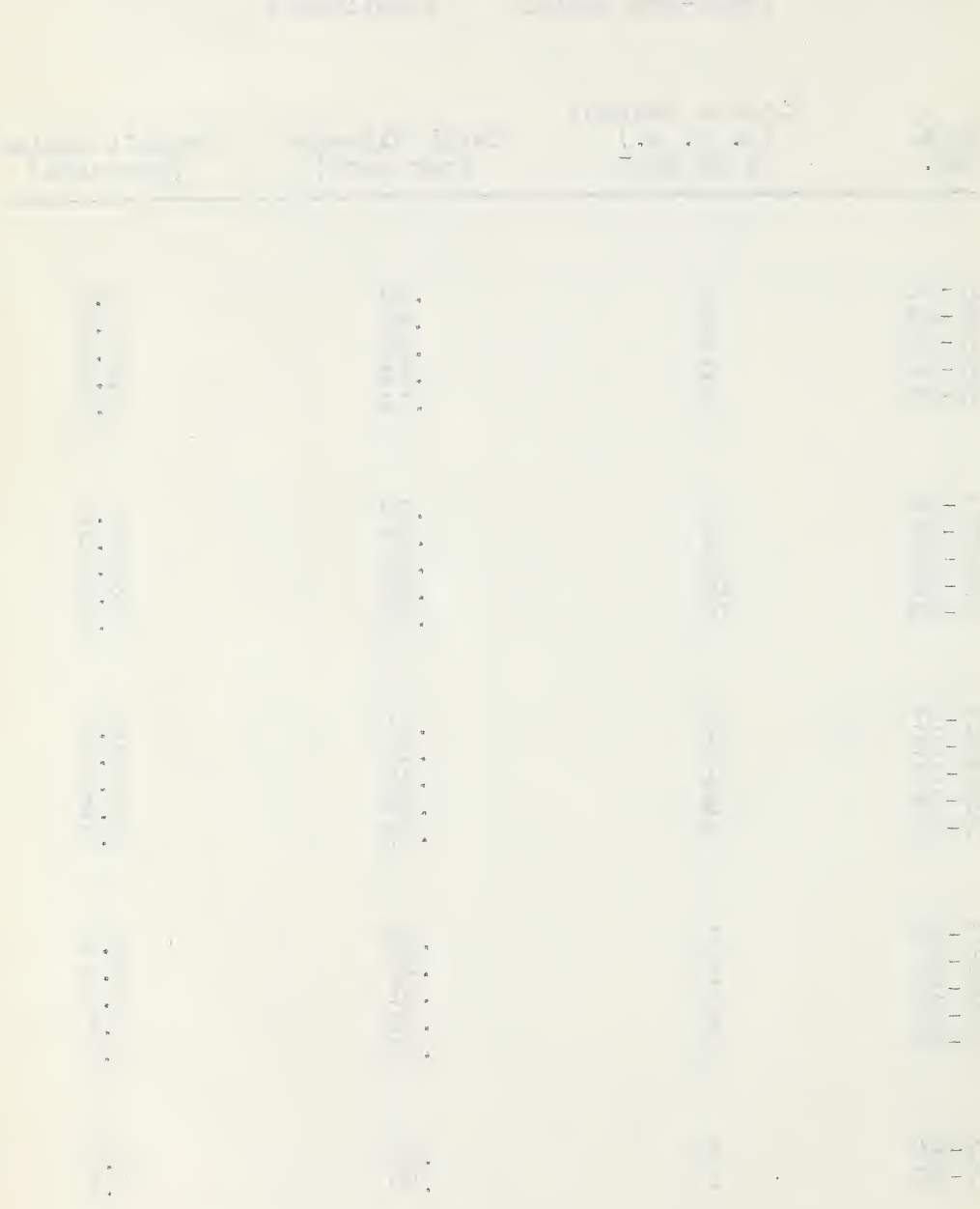

TABLE XIII. Some Analytical Data for Soil Samples

(oven-dry basis) (Continued)

Trial No.	Nitrate Content (p. p. m.) N as NO_3^-	Total Nitrogen (per cent)	Organic Matter (per cent)
58- 1	2	.19	4.6
58- 2	2	.19	4.6
58- 3	3	.28	6.9
58- 4	4	.55	12.9
58- 5	2	.33	7.0
58- 6	2	.22	4.8
58- 7	8	.55	13.2
58- 8	4	.25	5.7
58- 9	4	.25	5.7
58-10	2	.22	4.9
58-11	5	.24	5.3
58-12	2	.11	2.4
58-13	5	.16	3.8
58-14	3	.30	7.8
58-15	1	.14	3.2
58-16	5	.18	4.0
58-17	5	.18	4.0
58-18	1	.10	2.9
58-19	8	.12	3.1
58-20	4	.14	3.3
58-21	4	.14	3.7
58-22	4	.20	4.3
58-23	1	.14	3.3
58-24	4	.30	6.0
58-25	2	.30	6.9

TABLE XIV. Nitrate Accumulation by Various Methods

Trial No.	p.p.m. N as NO_3^- accumulated using Method 1	2	3
57- 1	43	21	27
57- 2	43	21	27
57- 3	40	56	54
57- 4	55	55	55
57- 5	103	95	67
57- 6	41	22	23
57- 7	41	22	23
57- 8	54	73	61
57- 9	84	82	84
57-10	57	52	41
57-11	57	52	41
57-12	54	52	44
57-13	64	82	80
57-14	48	59	54
57-15	64	55	54
57-16	64	55	54
57-17	54	47	48
57-18	55	39	43
57-19	74	51	51
57-20	81	64	64

(Continued)

TABLE XIV. Nitrate Accumulation by Various Methods

(Continued)

Trial No.	p.p.m. N as NO_3^- accumulated using Method 1	2	3
57-21	35	58	53
57-22	69	141	113
57-23	48	50	38
57-24	36	25	35
57-25	36	25	35
57-26	41	49	39
57-27	53	37	29
57-28	41	84	53
57-29	42	16	26
57-30	62	37	30
57-31	89	62	63
57-32	52	24	23
57-33	45	37	36
57-34	55	55	63
57-35	73	43	43
57-36	54	74	66
57-37	66	37	37
57-38	45	42	63
57-39	42	50	31
57-40	42	50	31
57-41	87	55	69
57-42	57	45	38

(Continued)

TABLE XIV. Nitrate Accumulation by Various Methods

(Continued)

Trial No.	p.p.m. N as NO_3^- accumulated using Method				
	1	2	3	4	5
58- 1	72	80	100	42	57
58- 2	72	80	100	42	57
58- 3	77	83	77	50	37
58- 4	91	49	45	45	69
58- 5	84	77	94	37	48
58- 6	77	36	38	28	57
58- 7	99	30	22	80	99
58- 8	69	72	94	43	77
58- 9	69	72	94	43	77
58-10	64	58	65	17	22
58-11	78	89	60	20	38
58-12	67	24	22	28	36
58-13	77	68	69	24	34
58-14	83	22	17	38	66
58-15	77	73	75	22	57
58-16	77	55	46	29	30
58-17	77	53	46	29	30
58-18	24	7	14	18	17
58-19	147	13	6	5	11
58-20	82	14	7	32	49
58-21	11	3	1	5	15
58-22	69	17	12	43	73
58-23	60	18	16	18	48
58-24	70	60	49	29	36
58-25	88	22	18	44	69

Note: Methods 1, 2 and 3 are expressed on air-dry basis.
Methods 4 and 5 are expressed on oven-dry basis.

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